



Suitability of litter amendments for the Australian chicken meat industry

by Mark Dunlop, Samuel Cockerill, Priscilla Gerber,
Steve Walkden-Brown & Nalini Chinivasagam
April 2020



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Chicken Meat

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**Summary of industry consultation
and selected outcomes of the literature review**

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Researcher Contact Details

Name:	Steve Walkden-Brown	Name:	Mark Dunlop
Address:	University of New England ARMIDALE NSW 2351	Address:	203 Tor St TOOWOOMBA QLD 4350
Phone:	02 6773 5152	Phone:	07 4529 4280
Email:	swalkden@une.edu.au	Email:	mark.dunlop@daf.qld.gov.au

In submitting this report, the researcher has agreed to AgriFutures Australia publishing this material in its edited form.

AgriFutures Australia Contact Details

Building 007, Tooma Way
Charles Sturt University
Locked Bag 588
Wagga Wagga NSW 2650

02 6923 6900
info@agrifutures.com.au
www.agrifutures.com.au

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Foreword

The Australian chicken meat industry is continually investing in research, development and extension of production practices that improve animal welfare, animal health, food safety, product quality and cost effectiveness associated with chicken meat production. This involves considering production techniques that are used overseas to see whether they might deliver benefits in the Australian context.

This project focused on litter amendment products, which are used overseas during the rearing of meat chickens. Litter amendments are primarily used to manage ammonia volatilisation, especially when litter is reused, but also provide antimicrobial and environmental benefits, and increase the nutrient value of spent litter.

The purpose of this report is to present the outcomes of consultation with representatives and stakeholders of the Australian chicken meat industry, and to summarise key findings from a literature review on litter amendments. While litter amendments are widely used in some countries, Australian practices are markedly different. In particular, rates of litter reuse are minimal, which effectively removes the need to use litter amendments for ammonia control. Pressure on litter supplies could alter this situation, but not in the foreseeable future. Nonetheless, further research and cost-benefit analysis on litter amendments is justified to ensure that the chicken meat industry has documented information about a variety of ammonia-control strategies in case they are needed because of bedding shortages or other reasons that require litter reuse. Litter amendments could also have a role in complementing existing strategies for addressing ammonia, chicken health challenges, and food safety-related pathogens.

This report for the Chicken Meat RD&E program adds to AgriFutures Australia's diverse range of research publications. It forms part of our 'growing profitability' arena (Arena 3), which aims to enhance the profitability and sustainability of our levied rural industries. For the Australian chicken meat industry, RD&E supports the industry to provide quality wholesome food to the nation.

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Mr John Smith

General Manager, Research
AgriFutures Australia

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Abbreviations

Alum	aluminium sulfate
NH ₃	ammonia
NH ₄ ⁺	ammonium
PG	Poultry Guard (Oil-Dri Corp. of America, USA)
PLT [®]	Poultry Litter Treatment (Jones-Hamilton Co., USA)
WHS	workplace/worker health and safety

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Executive summary

What the report is about

Currently, there is considerable pressure on the supply of fresh bedding material for meat chickens in Australia. If supplies to meat chicken farms are not sufficient, then there will be a greater need to reuse litter. Consequently, the industry will need to consider the use of litter amendments to help manage the key issues of excessive ammonia production and pathogen load. In Australia, very little is known and very few people in the industry have had any experience using litter amendments. This report has been written to increase knowledge about litter amendments and how they can be used safely and effectively to control ammonia concentration in meat chicken sheds, particularly from reused litter. This report also includes information about the potential of litter amendments to contribute to beneficial antimicrobial and environmental outcomes and higher nutrient value of spent litter. Information was obtained through a consultation process with Australian chicken meat representatives and stakeholders as well as a literature review. The purpose of this report is not to promote uptake of litter amendments, but to improve knowledge about litter amendment products and reuse practices based on experience and research in Australia and overseas. The consultation process also refined the scope for the literature review, and solicited predictions about potential future use of litter amendment products.

Who is the report targeted at?

The report is written for RD&E decision makers, researchers, producers, consultants and regulators with interests in litter management practices, chicken health, food safety, and animal welfare.

Where are the relevant industries located in Australia?

The Australian chicken meat industry involves the participation of about 700 farms and 40,000 employees. Chicken meat is produced at sites in all Australian states and are typically near major metropolitan centres. According to the Australian Bureau of Agricultural and Resource Economics, Australians consume about 50 kg of chicken meat per person per year, which is almost twice as much as any other type of meat. The strong demand for chicken meat is rising, and is a primary driver for industry growth.

Background

Litter amendment products are virtually unused in Australia because current practices do not require them. Potential benefits with litter reuse have raised questions about whether the Australian chicken meat industry should consider more widely adopting litter reuse, especially full reuse, given the current and potential future pressures around litter supply and a continually growing industry to meet local demand. With such little understanding of litter amendments in an Australian context, more information is needed for decisions about future industry direction and research.

Aims/objectives

The first objective of this report was to investigate, through industry consultation, the extent of the Australian industry's current knowledge and interest in litter reuse, and in using litter amendments. The second objective was to summarise information about litter amendments, with consideration about how and why the Australian chicken meat industry may adopt the use of litter amendments (which might be different to other countries, and could be affected by unique influencing factors).

Methods used

Information about litter amendments and their use by the Australian chicken meat industry was gathered from published literature, other information sources, and consultation with industry people and stakeholders. Information about litter amendments included the related topics of litter reuse, ammonia management, and disease/pathogen control (primary and secondary purposes for litter amendments, respectively). Industry consultation revealed the level of knowledge and practical experience with litter reuse and using litter amendments, as well as future perspectives on litter reuse and application of amendments.

Results/key findings

Consultation with Australian chicken meat industry representatives and stakeholders revealed that litter reuse practices are not widespread in Australia, and there is virtually no brooding on reused litter. Consequently, use of litter amendments in Australia is effectively non-existent.

Uptake of litter amendment products would firstly require:

- Adoption of full litter reuse, which is likely only if new bedding supplies become unavailable or cost-prohibitive
- Better availability of purpose-specific litter amendment products in Australia
- Defining and documenting best management practices for using litter amendments (as supported by data and agreed to by experts)
- Support by customers, environmental regulators and food safety authorities
- Data demonstrating efficacy, safety and cost effectiveness of litter amendments in the Australian context.

The literature review concisely summarised information about a variety of litter amendments, including acidifiers, adsorbents, inhibitors, microbial/biological products, and alkaline materials. Information about ammonia was also included because it is the primary reason for using litter amendments. The literature review included findings and recommendations from research and commercial experiences with litter amendments, and the currently recommended methods for using litter amendments (as applied in overseas meat chicken production).

Implications for relevant stakeholders

Litter amendments are available overseas, but are relatively difficult to obtain in Australia. There is minimal need for litter amendments currently in Australia due to the practice of brooding on new bedding materials. Current litter management and ventilation practices are effective for managing ammonia without the need for litter amendments.

Based on previous research that some litter amendment products could deactivate or reduce diseases, viruses and food safety-related pathogens, there might be opportunities to further research a possible role for litter amendments to complement existing disease management and treatment practices. In particular, research should focus on diseases that are difficult to manage under commercial conditions.

Pressure on new bedding supplies could prompt wider uptake of litter reuse practices; however, there is no consistent documentation on agreed best practices, especially about full litter reuse. To ensure that all meat chicken farmers, integrators, and other stakeholders have the necessary information to make informed decisions, there needs to be a consistent methodology on litter reuse, possibly including litter amendments. Until consistent litter reuse practices are defined, it is difficult to determine the cost effectiveness, application practices, and expected benefits of litter amendments.

Recommendations

The following recommendations are based on outcomes from industry consultation and the literature review:

1. The Australian chicken meat industry should define best management practices for partial and full litter reuse based on data and agreement from a panel of industry representatives, stakeholders and overseas experts who have knowledge of and experience with litter reuse
2. The literature discussed in this report should be used to support future research and discussions about litter reuse practices and use of litter amendments in Australia
3. Experimental trials should be undertaken in Australia to quantify the efficacy, safety and cost effectiveness of litter reuse and litter amendments for ammonia control, especially during brooding
4. Experimental trials should be undertaken in Australia to evaluate the efficacy of litter amendments to address health and food safety challenges, either as a standalone treatment or to complement existing treatment or management strategies.

Introduction

Litter amendments are products that may be used to change the chemical, physical or biological properties of poultry litter. Their primary use is to improve the chicken's environment by reducing ammonia emissions, especially during brooding, although they have also been used to reduce challenges associated with diseases or pathogens, and to improve the fertiliser value of spent litter. Reducing ammonia emissions and disease challenges with litter amendments may improve welfare and productivity (e.g. weight gain, feed conversion ratio, mortality) while reducing heating and ventilation costs.

Litter amendments are widely used by meat chicken and turkey farmers in some countries, e.g. the USA (Pursswell et al. 2013), but reported use of these products in Australia is almost non-existent. This is largely due to differences in production methods, climate, and availability of new bedding materials. Many factors influence the use of litter amendments, including the ability to achieve sufficient benefits to justify the extra costs. These factors include:

- Litter management practices (especially litter reuse from one grow-out to the next)
- Husbandry practices, especially brooding on reused litter
- Cost and availability of new bedding
- Cost and availability of litter amendment products
- Cost of electricity and gas (for heating and ventilation)
- Ability to dispose of spent litter
- Grow-out scheduling, especially the downtime between grow-outs
- Shed and ventilation system design and management
- Length of the grow-out, especially for turkeys and meat chicken breeder flocks
- Availability of on-farm machinery or external contractors to apply amendment products
- Climate and weather
- Recent incidences of disease, high pathogen levels or litter beetles.

Litter reuse is not widely practised in Australia (Runge et al. 2007; Wiedemann 2015; Watson and Wiedemann 2018), which is one of the reasons why litter amendments are rarely used here. Litter reuse is almost a prerequisite for the use of litter amendments. If new bedding is used for brooding, there is generally insufficient manure and ammonia generation to justify the use of litter amendments (unless being used for another purpose). If market drivers require litter reuse in the future, litter amendments may be considered.

It is not essential to use litter amendments, as has been demonstrated through the successful rearing of millions of meat chickens in Australia. The risks associated with ammonia, disease, and pathogens are a normal part of rearing meat chickens. They are currently minimised successfully with other management strategies, such as increasing ventilation, using new bedding for brooding, and applying strict biosecurity protocols. The choice to use litter amendments to complement or replace these existing practices will be influenced by comparative costs with other strategies.

While there are benefits associated with using litter amendments, they also introduce new management challenges and risks. Litter amendments are not a standalone treatment. They rely on other complementary practices, such as litter preconditioning (e.g. de-caking, heat treating, drying), shed preparation (e.g. heating, ventilating, cleaning and sanitising) and strictly following routine biosecurity practices. Litter amendments must be applied according to manufacturer's recommendations, which may require additional machinery on the farm or use of contractors. Timing of application is critical, with some products needing to be applied within a day of chick placement, while other products need to be applied several days to a week before. Finally, some litter amendments can be harmful to chickens if used incorrectly, which emphasises the need to strictly follow manufacturer's recommendations.

The Australian chicken meat industry has had relatively limited experience with litter reuse, and even less experience with litter amendments. For this project, key people and stakeholders in the industry were consulted to investigate and clarify their experiences, current knowledge and future perspectives on litter reuse and litter amendments. Influencing factors and need for more information on the use of litter amendments were also discussed. To support decisions about potentially using litter amendments in Australia, information about litter amendments was compiled and has been summarised in this report.

Objectives

The first objective of this report was to investigate, through industry consultation, the Australian industry's current state of knowledge and interest in litter reuse and using litter amendments. The second objective was to summarise information about litter amendments, with consideration about how and why the Australian chicken meat industry might adopt the use of litter amendments (which might be different to other countries, and could be affected by unique influencing factors).

Methodology

Industry questionnaire

A questionnaire that included a series of open questions (Appendix 1) was sent to key people and stakeholders in the Australian chicken meat industry to obtain information about how and why the industry might adopt litter reuse and the use of litter amendments. Key people included farming managers, veterinarians, service people, litter contractors and poultry consultants who were aligned with the major integrator companies and could provide responses based on national or state-specific experiences and trends. They were asked to share their knowledge, experience, and perspectives about litter reuse and litter amendment products.

Respondents provided written or verbal responses to the questions, and the research team followed up with respondents if clarification or extra information was needed. Results were collated and summarised by categorising the responses or by listing any comments.

Literature review

Information about litter amendments, and related topics of litter reuse, ammonia management, and disease/pathogen control (primary and secondary purposes for litter amendments, respectively) was gathered from published literature, conference/workshop presentations, product information, product suppliers, and discussions with key people with experience and insight into the use of litter amendments.

Information about each of the included litter amendments was summarised into the following categories:

- Key ingredients and chemical formulations
- Pre-application preparations
- Application rates
- Application methods
- Considerations for ongoing use and safety precautions.

Industry and stakeholder consultation

A questionnaire (Appendix 1) gathered information from key people and stakeholders in the Australian chicken meat industry about litter reuse practices and the use of litter amendments. Eleven responses were received. Respondents were veterinarians, farming managers, service people, litter contractors or poultry consultants. Each was aligned with at least one of seven integrator companies. Responses represented national or state-specific experiences and trends for NSW, VIC, SA, TAS and QLD.

Rates of litter reuse in Australia were expected to be limited (Runge et al. 2007; Wiedemann 2015). Rather than collect statistics on industry practices, the questionnaire included a series of open questions for respondents to share their knowledge, experience and perspectives. Nonetheless, receiving similar feedback from multiple respondents was considered to be indicative of relative importance/rating.

The following sub-sections provide summaries of questionnaire responses. NOTE: *Percentages given in the figures (below) indicate the percentage of respondents giving that answer, not the percentage of national production.*

Region represented by respondents and current litter practices

The majority of respondents provided responses that were state-specific, but a few gave a national perspective (Figure 1).

Most respondents indicated that they never reuse litter for multiple grow-outs (Figure 2) or might reuse litter only when necessary to address a specific issue, such as not being able to source new bedding. Partial litter reuse is routine for some farms contracted to particular integrators in south-eastern QLD and Sydney. Full litter reuse practices are not routinely used on any farms.

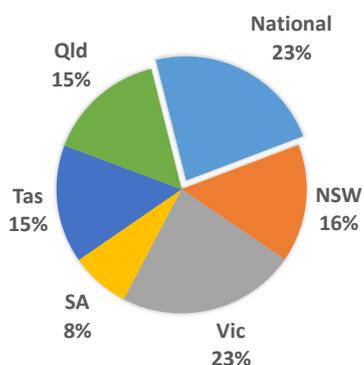


Figure 1: Regions represented by the respondents

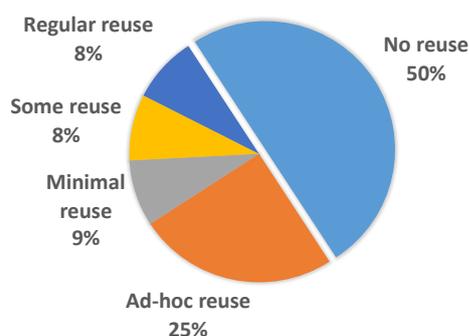


Figure 2: Types of litter reuse practices used by the respondents

For those with experience with partial litter reuse, procedures routinely used included:

- De-caking or removing some litter, especially from underneath drinkers or near the cool-pads
- Forming the litter into heaps/piles or windrows
- Leaving litter for 3-4 days (some respondents indicated that it should be turned)

- Ensuring sufficient temperature (55 °C)
- Respreading in the grow-out end of the shed
- Placing new bedding in the brood section, with fresh bedding extending 5–10 m past the brood-curtain
- Heating and ventilating the shed before placing chicks
- Using the brood-curtain and configuring operation of the ventilation system to isolate chicks from the reused litter, and any ammonia it might produce.

Respondents were asked about the new bedding materials they use because it might be relevant to future trends in litter reuse and the use of litter amendments. Respondents gave percentages of different litter materials being used, which gave an overview of the different materials (Figure 3) across the industry. The most common bedding material was wood shavings (pine or hardwood), followed by rice hulls, sawdust, and straw. Others included sugar cane byproducts and recycled timber (chipped or shredded).

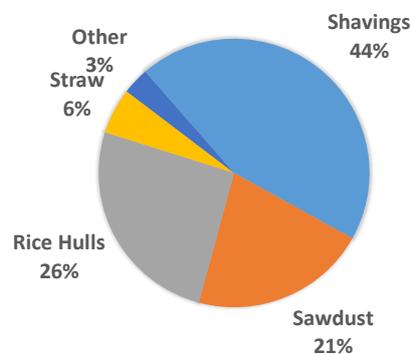


Figure 3: Utilisation of bedding materials by the respondents

Factors affecting litter reuse

Because litter reuse is a prerequisite for using litter amendments, respondents were asked to explain the factors that they believed influenced farm-based decision making for litter reuse. The responses (Figure 4) suggested that the greatest influence was contract conditions stipulated by the integrator, followed by factors relating to costs, animal husbandry, and farm management. The farmer's personal choice and preference for litter reuse was also important. Other factors not shown in Figure 4 included ammonia, ability to sell/dispose of spent litter, farmer knowledge, labour availability, shed type (tunnel vs conventional), and acceptance by environmental and food safety regulators.

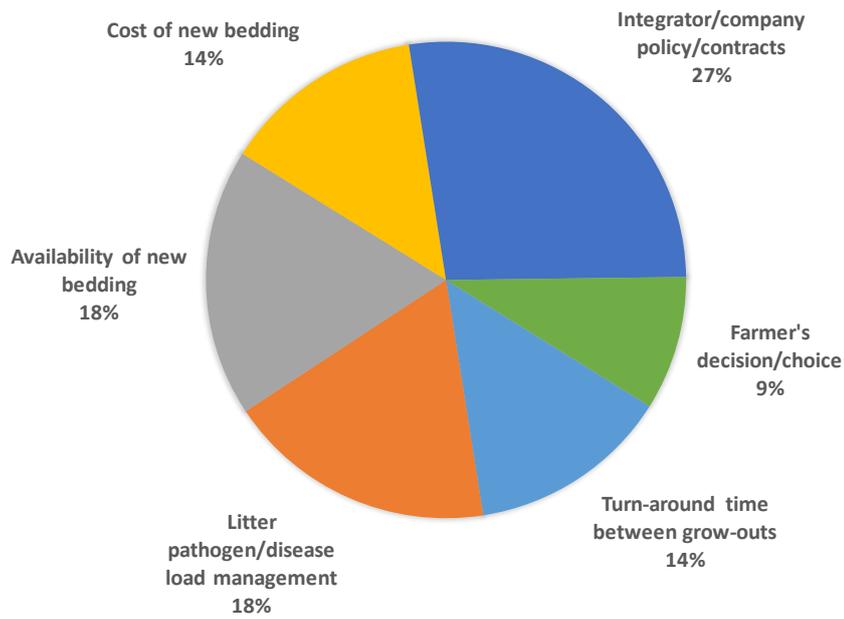


Figure 4: Leading factors believed to influence on-farm decision making for litter reuse

Respondents were also asked to list the risks they believed were associated with litter reuse. The most common related to ammonia, diseases, pathogens, odour, and inability to successfully heat-treat litter between grow-outs (Figure 5).

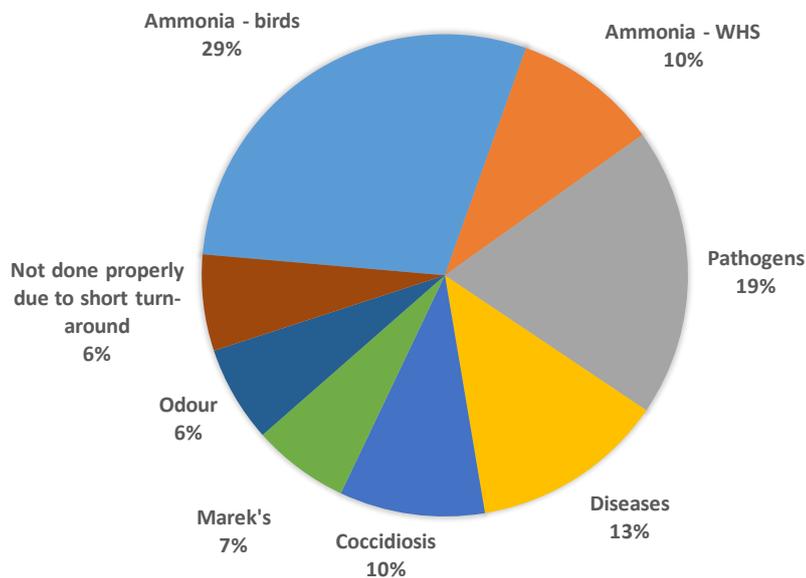


Figure 5: Leading concerns and perceptions with litter reuse

Other perceived risks and fears associated with litter reuse included:

- Dust (from a worker health and safety (WHS) perspective)
- Endotoxins (from a WHS perspective)
- Higher heating costs and the need for increased minimum ventilation
- Need for longer downtime between grow-outs
- Necrotic enteritis
- Litter beetles
- Wet litter
- Inability to get sheds clean enough for next grow-out
- The process not being done properly because of operator error
- The process not being done to integrator’s requirements
- Regulator concerns about food safety
- Customer concerns about food safety
- Higher labour requirement (than new bedding)
- Environmental and planning approval conditions may be violated
- ‘Fear of the unknown’ (for farmers who currently do full clean-outs and use new bedding).

Respondents described benefits that they had observed from reusing litter (Figure 6) related to better chicken comfort and cost-effectiveness. The extra depth of litter retained when reusing litter was thought to improve insulation and litter moisture management, making litter more consistently friable. Reusing litter reduced costs associated with buying new bedding and also increased the value of spent litter. One respondent also mentioned research demonstrating that reusing litter lowered food safety-related pathogen risks.

Consequences of reusing litter were also reported (Figure 7). Ammonia was the most common, though one respondent with several hundred batches of partial litter reuse experience noted that ammonia issues were very rare. Other issues related to worker health and safety (higher exposure to dust, ammonia and endotoxins), the need for additional labour, unpredictable benefits/outcomes, higher pathogen build-up, and more dust.

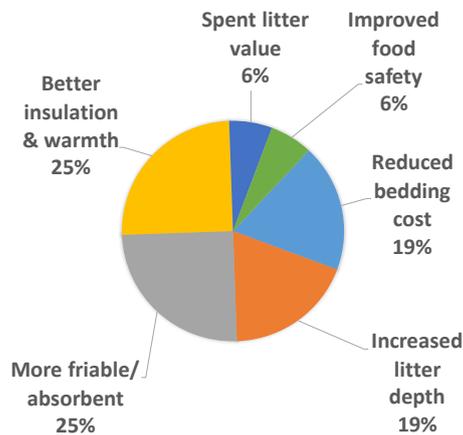


Figure 6: Benefits observed while reusing litter

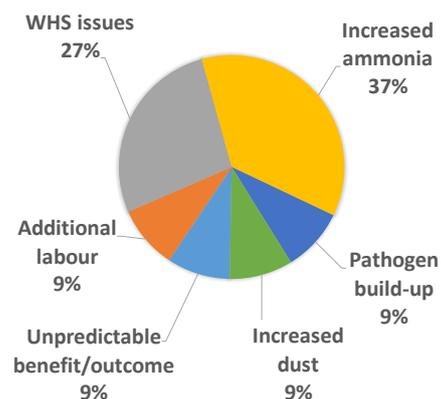


Figure 7: Consequences observed while reusing litter

Australian chicken meat industry experiences with litter amendments

Respondents indicated that no litter amendments are routinely used. Several respondents have previously used or trialled litter amendments for specific issues, such as being unable to source new bedding or to address a disease or pathogen. The only products reported to have been trialled were sodium bisulfate, pH natural (Hearts of Nature, USA), Stalosan[®]F (Vilofoss[®], Denmark), clay-based products, hydrated lime, BiOWiSH[®] (BiOWiSH[®] Technologies, USA), and diatomaceous earth. Some respondents were also aware of but had not used other products, including Alum, PLT[®]-Poultry Litter Treatment (Jones-Hamilton Co., USA) and Poultry Guard (Oil-Dri Corp. of America, USA).

Reasons for the use of litter amendments being discontinued included:

- Considered unnecessary
- Unnecessary cost
- No observed or predictable benefit
- Additional labour requirement
- Worker health and safety (especially relating to handling acidic products)
- The products used only to address a specific, acute issue.

It was evident that most respondents had limited knowledge of litter amendment products, including those available, where they could be bought, how they should be used, and expected outcomes. Some respondents believed that litter amendments would be effective at reducing ammonia, and a few believed that certain amendments would be effective against diseases and pathogens. These responses reflected the litter management practices in Australia, where full litter cleanouts are the most common and preferred option. Litter amendments have not been used because there was no need.

Future directions with litter reuse and litter amendments

The questionnaire asked participants about their predictions for uptake of litter reuse practices and litter amendments. Most believed that it would be more likely in the future (Figure 8 and Figure 9, respectively). Some respondents indicated it would be more likely, but conditional on acceptance by integrators, customers, and regulators (environmental and food safety).

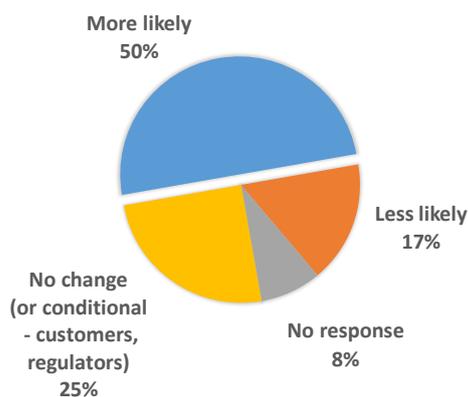


Figure 8: Predictions about uptake of litter reuse practices in the future

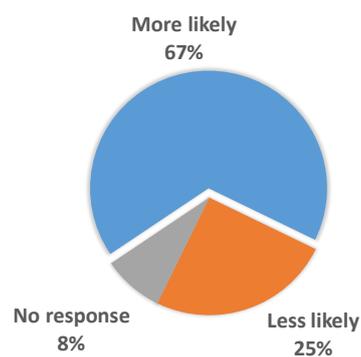


Figure 9: Predictions about uptake of the use of litter amendments

Reasons for adopting litter reuse practices and litter amendments included:

- New/alternative bedding supplies are becoming more difficult to source or supplies are limited
- Increasing cost of new bedding
- Spent litter is difficult to sell or dispose of
- A growing interest in using deeper litter
- Improved cost effectiveness
- More stringent regulations about using spent litter as fertiliser
- Changing attitudes to biomass use
- Smaller carbon footprint
- Litter amendments more likely due to more stringent ammonia control requirements.

In addition to these reasons for adoption, respondents reported some industry issues and situations could potentially be addressed or improved by using litter amendments, including:

- Odour
- Environmental impacts
- Low economic value of spent litter (could be improved by retaining more plant-available nitrogen)
- Antibiotic usage
- Coccidiosis
- Ammonia
- Litter moisture
- During disease outbreaks, might be useful as a complementary treatment
- When it isn't possible to clean out spent litter or source fresh bedding.

Reasons for adoption of litter reuse practices and litter amendments being less likely included:

- Grower contracts don't cover litter treatment costs
- Unknown future bedding supplies (if no restriction, no need for litter reuse or amendments)
- Integrator requirements for full clean-out and new bedding each grow-out
- Difficulty with cleaning and sanitising sheds when litter is not removed
- Concerns about perceptions
- Lack of acceptance by integrators
- Lack of acceptance by customers
- Lack of acceptance by welfare standards
- Lack of acceptance by environmental regulators
- More labour and skill required to successfully treat and prepare litter for reuse
- More or different machinery and capital required to adopt litter reuse
- Difficulties with arranging multiple contractors between grow-outs.

Additional information required to support industry adoption

Participants were asked if there were any litter amendments topics that they would like extra information on, and included in a literature review. Topics included:

- Workplace health and safety considerations
- Cost
- Availability
- Application methods
- What to do with short turnaround times
- Strategies to reduce crude protein and eliminate excess protein from litter

- Potential for reducing antibiotic use
- Efficacy for ammonia control
- Efficacy for coccidiosis control
- Efficacy for *Salmonella* control
- Efficacy for *Campylobacter* control
- Efficacy for *Clostridium* spp. control
- Efficacy for odour control
- Effects on litter moisture
- Effects on footpad dermatitis.

Participants were asked whether a literature review should include breeder farms as well as grow-out farms. The majority responded that the focus should be solely on grow-out farms (58% grow-out only; 17% should include parent flocks; 25% gave no response). One respondent who thought that breeder farms should be included suggested that litter amendments may be useful for long-term ammonia control due to the longer duration of parent flock cycles.

Participants were also asked whether they were likely to change their current litter management practices (of litter reuse and use of litter amendments) if they received more information. Responses were well balanced (Figure 10), with about equal numbers indicating that they were either likely or unlikely to change. Most responses were conditional, citing external influences, including:

- pressure to retain full litter clean-out practices (on grounds of welfare, environmental impacts or food safety)
- new bedding supplies and costs
- changing attitudes to biomass use
- quality of the science to support practice change.

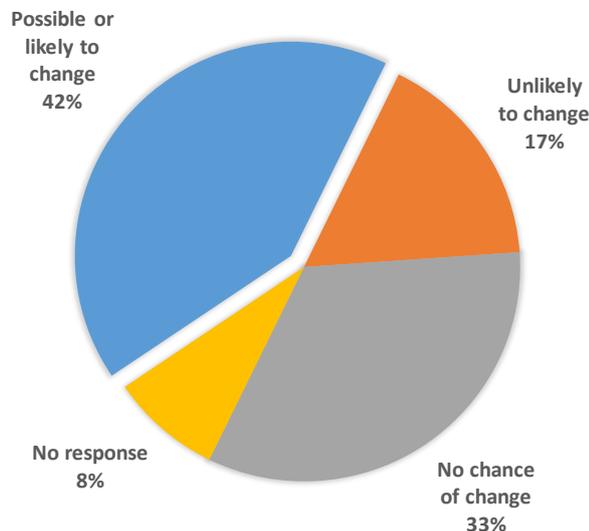


Figure 10: Likelihood of respondents making changes to their current litter management practices if they receive more information about litter reuse and litter amendments

At the end of the questionnaire, extra comments about litter reuse and litter amendments that should be considered when planning for adoption or further research included:

- Reuse litter would not be used in brooding areas (partial reuse only)
- There are significant welfare risks associated with ammonia
- There are food safety risks if reused litter is not pasteurised properly due to short turn-around times or operator error
- There are disease/pathogen risks to the chickens if reused litter is not pasteurised properly due to short turn-around times or operator error
- There are virus risks with litter reuse due to difficulty de-activating with short-term pasteurising
- Litter reuse is unlikely to be used on breeder farms
- Information and documented methods are needed in case the adoption of litter reuse and use of amendments becomes necessary
- Litter reuse may reduce the risk of foreign material and weed seeds in new bedding, which can be a problem when disposing of spent litter
- There may be limitations on spreading spent litter if chickens have been fed meat meal—there would be reduced spent litter disposal volumes with litter reuse
- Litter amendment products are not readily available in Australia
- Litter reuse may influence gut health
- *Salmonella* swab testing should be undertaken when making decisions about whether to reuse or not
- Low-protein diets are now more viable and will reduce excess protein and subsequent ammonia issues
- On-farm labour requirements is a major consideration
- Litter reuse and amendments may also be applicable in the layer industry
- Future litter reuse and use of amendments is most likely to be determined by policies and direction of processors, environmental regulators, food safety regulators, customers and welfare accreditation schemes
- Litter reuse won't be used with short turn-around times, which are required to allow more chickens/year to offset farm capital costs
- The Australian chicken meat industry should be prepared for litter reuse and amendments
- Adoption of litter reuse could result in higher condemnations and downgrades due to food safety and meat quality issues
- Australian industry needs firm data to support adoption of new methods
- Industry adoption will be enhanced with information days for farmers, and presentations at Poultry Information Exchange (PIX), PIX workshops and Australian Veterinarian Poultry Association meetings.

Summary and implications of the industry questionnaire

It is clear from the industry responses that there is minimal litter reuse, apart from in two regions where partial litter reuse practices are used. There is no routine practice of brooding on reused litter and, consequently, there has been no real need for litter amendments. Risks associated with ammonia are already minimised by investing in new bedding materials for brooding, and using ventilation to dilute ammonia and keep it below recommended levels.

Short supplies and high costs of new bedding have led to partial litter reuse practices. Most respondents suggested this is a trend that is likely to extend more broadly across the industry, and it is likely that there will be wider uptake of litter reuse practices.

Due to low rates of litter amendment use, the market for these products has not developed in Australia, and many of the products are difficult to obtain, even though they may be extensively used in other countries.

Some questionnaire responses indicated that customers, regulators and other stakeholders might have concerns or perceptions about risks associated with litter reuse, and that these concerns might be a barrier to uptake. This point is of little consequence because the industry is not moving to uptake litter reuse or use litter amendments above current levels.

It is anticipated that new bedding supplies will not meet industry needs, and litter reuse will become necessary on more farms. Those who reuse litter have described benefits, including lower costs, better insulation properties, and easier litter moisture management. Although there are some benefits, litter reuse requires additional preparation and careful management to minimise associated risks.

Litter reuse practices should be broadly discussed and shared across the industry, with agreed best practices being documented. These practices should be developed in consultation with customers, regulators and stakeholders so they understand the processes, benefits and potential risks, and can support uptake of litter reuse. This will also ensure that the best practices are practicable, applicable and cover all the issues. Litter amendments should also be trialled in Australia, starting with methods that have been refined in other countries, so that the industry is prepared and confident about the safety of litter amendments if they be needed here in the future.

Litter amendments—literature review

The industry consultation process revealed that litter amendment products might one day be used in Australia, based on the prediction that rates of litter reuse are likely to increase. Litter amendment products are used extensively overseas, particularly the USA. The most commonly used products have been developed and tested to refine application methods, ensure safety, and maximise efficacy. Published test results and product documentation were reviewed to learn more about litter amendments for the Australian chicken meat industry. Detailed summaries of selected literature are provided in Appendix 2.

The following sections summarise the information about litter amendments. Several classes of amendments were identified (Shah et al. 2012), including:

- Acidifiers
- Adsorbents
- Inhibitors
- Microbial/biological products
- Alkaline materials.

Information about ammonia was also included in the literature review because it is the primary reason for using litter amendments. Successful use of litter amendments requires an understanding of how each product affects ammonia production.

Selected litter amendment products mentioned in the following sections are listed in Appendix 3, along with manufacturer recommended methods, application rate, and safety considerations.

The following information assumes that birds are being brooded on reused litter, which isn't the case in Australia.

Using litter amendments to manage ammonia in meat chicken sheds

Ammonia (NH₃) is a naturally occurring chemical that commonly exists as a liquid or gas. In meat chicken sheds, it commonly occurs as a gas. It is highly water soluble, has a characteristic, pungent smell, and at high concentrations can damage the health of chickens and farm workers. To minimise health risks, Australian animal welfare standards require ammonia to be kept below 20 ppm. Some farming schemes require the concentration to be kept below 15 ppm (RSPCA Australia 2013; Animal Health Australia 2017). Effects from ammonia exposure are dependent on the concentration and duration of exposure. In chickens, acute exposure to high concentrations can damage respiratory tracts or eyes. Ammonia exposure is also known to be detrimental to chicken growth rate and other production performance measures. The primary role of litter amendment products is to avoid the detrimental effects of ammonia.

In meat chicken sheds, ammonia is produced by stepwise enzymatic decomposition of the uric acid in fresh excreta. The decomposition process occurs because of microbial activity in the litter. When ammonia is produced, volatilisation occurs, which is how ammonia becomes an airborne gas in the chicken shed.

The concentration of ammonia in the air is affected by several processes (Figure 11) that occur:

- Within the litter to create ammonia
- At the interface between the litter and air, which regulates ammonia release into the air

- In the shed airspace, where ammonia is diluted by ventilation before exhaust fans remove it from the shed.

Understanding these processes is essential for managing and mitigating ammonia in meat chicken sheds. Realistically, it is not possible to influence the gas exchange interface at the litter surface, so controlling ammonia concentration relies on reducing ammonia formation within the litter and then using ventilation to manage the ammonia that is released.

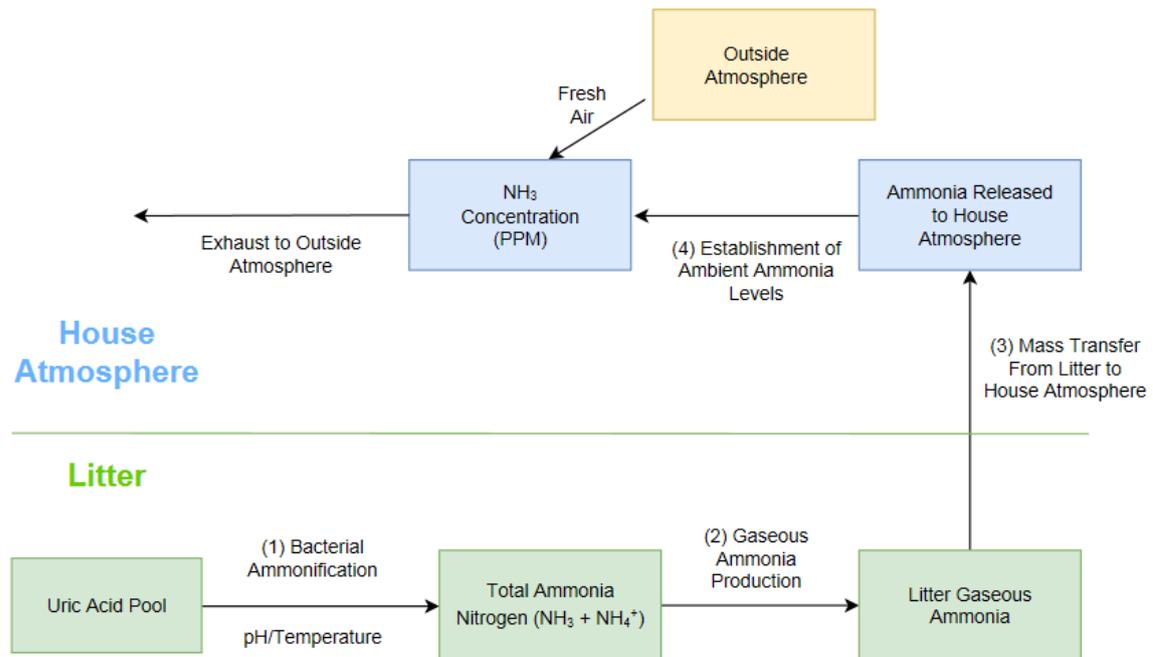


Figure 11: Ammonia gas production, mass transfer, and establishment of aerial gas concentrations within a meat chicken house (Elliott and Collins 1982)

Acidifying litter amendments

Uric acid is high in nitrogen (N). It is the primary source of N that microbes use to produce ammonia. When ammonia is formed in the litter, it either converts into a gaseous form or into ammonium (NH_4^+), which is a relatively stable form of nitrogen commonly found in fertilisers. To reduce the formation of ammonia, it is necessary to inhibit microbial decomposition of uric acid or to chemically alter the decomposition process to avoid ammonia being produced.

The acidity of the litter (measured using the pH scale from 0 to 14, where 7 is neutral, values less than 7 are acidic, and values greater than 7 are basic) has a strong influence on whether the ammonia is released as a gas or forms ammonium salts. When conditions are acidic (pH less than 7), there is a tendency to form ammonium salts, which means that less ammonia gas is produced. On the other hand, when conditions are basic (pH greater than 7), ammonia tends to be formed and released as a gas. This makes litter pH an important factor for in-shed ammonia concentrations.

Products that acidify the litter shift the ammonia/ammonium equilibrium towards producing ammonium. This reduces the amount of ammonia gas and also retains more N in the litter, which increases the fertiliser value of spent litter.

The most widely used litter amendment products are dry acids (Table 1), which reduce the litter pH.

Table 1: Acidifying litter amendment products

Chemical name(s)	Alternative names	Commercial product names (described in literature)
Sodium bisulfate		PLT® Poultry Litter Treatment (Jones-Hamilton Co., USA)
Aluminium sulfate	Alum	AL ⁺ Clear® (Chemtrade Logistics, Canada) (available in three grades: Liquid, Poultry Grade Alum (dry) and A7 (liquid))
Sulphuric acid		Poultry Guard® Litter Treatment (Oil-Dri Corporation of America, USA) in the form of an acidified bentonite clay
Ferric sulfate	Iron (III) sulfate	Klasp™ (Kemira Water Solutions, USA)
Ferrous sulfate [§]	Iron (II) sulfate	

[§]This chemical has been reported as toxic to chickens (Pescatore and Hartner-Dennis 1989).

One important consideration with acidifiers is when to apply them (Muhlbauer 2013). It has been reported that ferric sulfate products take longer to activate, and so should be applied 2–5 days before placing chicks (the exact length of time depends on the litter moisture content). In contrast, sodium bisulfate activates more quickly and should be applied 24 hours before placement. For all products, the manufacturer’s recommendations should be followed.

Inhibiting, biological and adsorbent litter amendments

Restricting microbial activity with inhibitors could also help to reduce ammonia formation. Minimal research has been published on inhibitors, but some have been found to be marginally effective, or are expensive (Singh et al. 2009; Shah et al. 2012). Stalosan®F (Vilofoss®, Denmark), mentioned during the industry consultation, has had a preliminary trial in Australia (Nutrifoss 2014). According to the manufacturer, Stalosan®F has inhibiting, drying and acidifying functions that are effective against a range of microbes and pest organisms. The preliminary trial indicated that Stalosan®F reduces ammonia concentration, but further research is required.

Biological products, such as Litter Life (Southland Organics, USA), are promoted as having a function that seeds the litter with beneficial microbes that initially may release ammonia, but in the longer term, convert the nitrogen into more stable forms (Southland Organics 2018). A potential short-term release of ammonia requires careful consideration for the timing of application to ensure that ammonia is low by the time chicks are placed in the shed. Further research is needed to assess the potential benefits of biological litter amendments.

Adsorbent litter amendments bind ammonia to the surface of the material, which reduces the amount released into the air. Several naturally occurring products, such as clay and peat, might be effective at adsorbing ammonia, but research has shown mixed results for ammonia control (Shah et al. 2012). Also, large volumes of the material are usually required, which reduces the affordability of using adsorbent litter amendments for ammonia control.

Other strategies for controlling ammonia in an Australian context

Litter amendment products are not the only way to manage ammonia in meat chicken sheds. Brooding chicks on new bedding greatly reduces ammonia-related risks at this critical stage of the grow-out cycle, justifying the Australian industry’s use of this management strategy.

Ammonia formation has been shown to be affected by litter temperature and moisture content (Miles et al. 2011). Ammonia increases with increasing temperature (up to 40 °C) and was greatest when litter moisture content was 37–51%. Litter temperature may be difficult to control; litter should be warm during brooding for the health and comfort of the young chickens. On the other hand, managing litter moisture content to avoid wet litter is a strategy that farmers can use to reduce the amount of ammonia released from the litter. This requires careful management of new bedding, ventilation, heating, evaporative cooling, drinking systems, nutrition, flock health and other production and environmental factors (Dunlop et al. 2016). Ventilation and heating are the primary tools for removing excess moisture from the litter. Recently tested ventilation strategies with powerful circulation fans and relative humidity control are showing promising signs of cost-effectively reducing the occurrence of wet litter (Mou et al. 2019), which might make them useful for managing ammonia.

Ventilation is also an essential tool for managing ammonia concentration in meat chicken sheds. The strength of ammonia that chickens experience is influenced by the shed ventilation rate and the amount of ammonia released from the litter (Figure 11). Increasing ventilation dilutes the amount of ammonia in the air and accelerates the removal of ammonia from the shed. There are limits to how much ventilation is possible, especially during brooding and at the start of the grow-out, because young chicks need warm and humid conditions. At this stage of the grow-out, excess ventilation to reduce ammonia concentration may be costly because of the need to provide more heat with gas or electric heaters; it might make the shed cold. Current Australian practices using new bedding reduces the need to use ventilation to manage ammonia. If litter reuse during brooding is adopted, the extra expense of using litter amendments will reduce the costs associated with extra ventilation and heating.

Other uses for litter amendments

Some litter amendments have been found to be effective at reducing the concentration of disease, virus, and food safety organisms:

- Giambrone et al. (2008) found that AL+Clear® (alum), PLT® (sodium bisulfate) and Poultry Guard® (acidified clay) were effective at reducing infectious laryngotracheitis (ILT) virus to below detectable levels in litter when used between grow-outs (note that five days of pasteurising heat treatment between had the same effect)
- McWard and Taylor (2000) found that AL+Clear® (alum), PLT® (sodium bisulfate) and Poultry Guard® (acidified clay) reduced darkling beetle counts in addition to improving feed conversion ratio, carcass quality, weight gain, and foot pad quality
- using acidifying litter amendments has been found to increase nitrogen retention in litter, which increases fertiliser value. Some products have also been found to reduce phosphorus runoff when litter is land-applied as a fertiliser (Moore et al. 2000; Moore et al. 2008; Eugene et al. 2015; Hunolt et al. 2015)
- in-house, laboratory and on-farm testing of Stalosan®F (by the manufacturer and their agents) suggests that it may be effective against infectious bursal disease virus (IBDV), avian influenza (H9N2; H5N1), Newcastle disease virus (NDV), *Salmonella*, *E. coli*, *Staphylococcus* spp. and *Campylobacter* (Gospodinov; Vilofoss; Nutrifoss 2019). Further, independent research under commercial meat chicken production conditions may be necessary to confirm these claims
- acidifying litter amendments have been found to delay onset and reduce counts of food safety pathogens, such as *Campylobacter* (Line and Bailey 2006; Rothrock Jr et al. 2008), although results on *Salmonella* and total bacterial count have been inconsistent (Line and Bailey 2006; Vicente et al. 2007; Williams and Macklin 2013).

These findings suggest that some litter amendment products, especially the acidifiers, may complement existing treatments and biosecurity practices for specific disease challenges, although

application methods and direct application of the products in the presence of the chickens may require specific testing and development of safe protocols. The use of some litter amendments has been found to be harmful to chickens (Wallner-Pendleton et al. 1986; Pescatore and Hartner-Dennis 1989; Myers et al. 2014), presumably when used or applied inappropriately, and serves as a warning that these products need to be used judiciously.

Conclusions

Feedback from industry and stakeholders clearly indicated that rates of litter reuse in the Australian chicken meat industry are limited, and that no chicks are brooded on reused litter. The preference is to use new bedding to minimise risks associated with ammonia exposure and to reduce concerns about disease and pathogen carryover. Consequently, use of litter amendments have been minimal, with only ad hoc use and trials to address specific, acute issues, usually associated with disease challenges. Concerns were also raised that uptake of litter reuse might not be acceptable to customers, environmental regulators, and food safety regulators.

A review of available information on litter amendments has demonstrated that products are available, at least overseas. Industry and research trials on many of these products show that the litter amendments are beneficial and safe when used appropriately. Some of the benefits included:

- Lower ammonia emissions with fewer associated risks
- Lower operating costs associated with new bedding
- Lower costs associated with heating during brooding
- Lower counts of disease, virus and food safety-related pathogens
- Higher nitrogen content and fertiliser value of spent litter.

Some of the potential challenges or issues associated with using litter amendments included:

- Chemical exposure when not applied appropriately (wrong timing or uneven application)
- Requirement for longer downtime between grow-outs
- Additional preparation of bedding compared with full litter clean-outs and using new bedding.

With minimal rates of litter reuse in Australia, the market for litter amendment products has not developed, especially for products that are specifically branded/ marketed and guaranteed for the purpose of controlling ammonia. Many of these products are difficult to obtain in commercial quantities and at cost-effective prices. However, the active chemicals in these products are used by other Australian industries and are therefore available, but there may be differences in chemical formulation and other properties, such as granule/particle size, that could alter their effectiveness for controlling ammonia emissions from poultry litter. There may be a need for trials to demonstrate the use of litter amendments (both branded and unbranded products) in meat chicken production to address Australian statutory regulations and concerns held by customers and regulators.

In the industry questionnaire, responses indicated that pressure on new bedding supplies will increase rates of litter reuse, although brooding on reused litter is unlikely in the foreseeable future. It is therefore unlikely that uptake of litter amendments will occur, at least not for ammonia control.

Implications

Litter amendments are available overseas, but are relatively difficult to obtain in Australia. However, if the Australian chicken meat industry showed interest in using them, availability of these products in Australia would very likely increase.

The primary use of litter amendments is to reduce ammonia emissions from reused litter during brooding. Australian litter use practices do not currently include full reuse, where chicks are brooding on reused litter. Therefore, uptake of litter amendments in Australia is unlikely in the foreseeable future.

Some litter amendments have also been found to be effective against specific diseases, viruses and food safety-related pathogens. Based on published overseas research, the Australian chicken meat industry has previously tried using litter amendment products to address acute disease challenges when necessary. An opportunity exists for further research into the possible role that litter amendments might have in complementing existing disease management and treatment practices, especially on diseases that are difficult to manage under commercial conditions.

Litter reuse is not common in the Australian chicken meat industry. Pressure on new bedding supplies may require wider uptake of litter reuse practices; however, there is no consistent documentation on agreed best practices, especially about full litter reuse. Defining consistent methodology for litter reuse, possibly including litter amendments, is a necessary prerequisite to give meat chicken farmers, integrators and other stakeholders the ability to make decisions about reusing litter. Until consistent litter reuse practices are defined, it is difficult to determine the cost effectiveness, application practices, and expected benefits of litter amendments.

Recommendations

The following recommendations are based on outcomes from industry consultation and the literature review:

1. the Australian chicken meat industry should define best management practices for partial and full litter reuse based on data from relevant overseas research and agreement from a panel of industry representatives, stakeholders and overseas experts who have knowledge of and experience with litter reuse
2. the literature discussed in this report should be used to support future research and discussions about litter reuse practices and use of litter amendments in Australia
3. experimental trials should be undertaken in Australia to quantify the efficacy, safety, and cost effectiveness of litter reuse and litter amendments for ammonia control, especially during brooding
4. experimental trials should be undertaken in Australia to evaluate the efficacy of litter amendments to address health and food safety challenges, either as a standalone treatment or to complement existing treatment or management strategies.

Appendices

Appendix 1: Industry consultation questionnaire:

Use of litter amendments to reduce ammonia-related risks in meat chicken sheds — including related litter management and preparation practices, and potential to reduce food safety organisms and other pathogens.

Mark Dunlop^{1,2}, Steve Walkden-Brown³, Nalini Chinivasagam¹, Cameron Stewart⁴, Priscilla Gerber³, and Sam Cockerill¹

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Background

AgriFutures Australia has funded a project (PRJ-011119) to review the use of litter amendments in an Australian context and to consult with industry about current and future use of amendments and other relevant litter management issues, especially regarding reused litter.

Litter amendments are considered to be chemicals/compounds/materials that are primarily used to reduce ammonia production, but may also have secondary benefits in terms of reducing food safety pathogen loads, and other pathogen loads in litter. Some amendment products reported to be in use overseas include *Poultry Litter Treatment (PLT)*, *Alum*, *Poultry Guard*[®], *AL⁺Clear-A7*[®], *AL⁺Clear*, and *PROTRAX*[™] (Zoetis).

Issues/considerations relating to litter amendments and litter reuse include:

- Cost of amendments vs fresh bedding costs (assuming amendments won't be used with fresh bedding)
- Availability of litter amendments in Australia – Including ease of sourcing.
- Approval to use amendments in poultry production (e.g. APVMA registration)
- Value/safety/suitability of spent litter for subsequent end-uses if containing amendments
- Worker safety in applying amendments or exposure during a grow-out
- Longevity of amendments and need for re-application during a grow-out
- Effect of amendment chicken gut flora diversity
- Health risk associated with ammonia and pathogens/diseases
- Food safety related risks (chemical and/or microbial contamination)
- Industry, policy or community drivers to reuse litter
- Approval/marketing schemes (e.g. welfare)
- Carbon footprint and lifecycle sustainability
- Extra inputs to prepare litter for reuse compared to fresh bedding
- Potential impacts on antibiotics production.

¹ Department of Agriculture and Fisheries, Queensland Government, Toowoomba

² Contact mark.dunlop@daf.qld.gov.au, m. 0409 583 005

³ University of New England, Armidale

⁴ CSIRO Australian Animal Health Laboratory, Geelong

Questions for integrators, farming managers & growing companies, and associated industry professions (e.g. vets, litter suppliers)

1. Does your operation currently reuse litter on farms?

- 1.1. What is the level of litter reuse within your operation (% of flocks)?
- 1.2. What are the proportions of bedding materials used in your operation:
 - 1.2.1. Shavings? _____% (pine/hardwood)
 - 1.2.2. Sawdust? _____% (pine/hardwood)
 - 1.2.3. Rice hulls? _____%
 - 1.2.4. Straw? _____%
 - 1.2.5. Peanut shells? _____%
 - 1.2.6. Other? _____% (please specify)
- 1.3. What factors determine if litter is reused or not?
- 1.4. Is it full litter reuse (brooding on reused litter), or partial litter reuse (fresh shavings for brooding)?
- 1.5. Do you perceive any risks associated with litter reuse?
- 1.6. What fears/perceptions exist relating to litter reuse?
- 1.7. How do farms prepare/treat the litter for the next grow-out (pasteurise, amendment or not)?
- 1.8. If yes, do they use litter amendment products, and which products do they use?

2. Has your operation used litter amendments in the past?

- 2.1. What product/s were used?
- 2.2. How were they used?
- 2.3. Do you recall the cost and application rates of the product?
- 2.4. Did the use of litter amendments stop for and reason?

3. Has your operation reused litter in the past?

- 3.1. Was it **full reuse, or partial reuse**?
- 3.2. What level of reuse was practiced within the operation? (e.g. % of flocks)
- 3.3. What **benefits and consequences** were experienced?
- 3.4. What **'hazards'** were identified, and the **frequency** that these were experienced?
- 3.5. Why did litter reuse **stop**?

4. What do you know about litter amendment products

Product	Heard of them? (Y/N)	Think it's effective for ammonia?	Think it's effective for pathogens?	Other Comments (benefits/ challenges/risks)
Alum				
AL+Clear (dry)				
AL+Clear-A7® (liquid)				
Poultry Litter Treatment (PLT)				
Poultry Guard®				
PROTRAX™				
Other products?				

5. **Please explain what you know about the efficacy of litter amendments for:**
 - 5.1. **Ammonia** control
 - 5.2. Potential to also contribute to reducing **food-safety** related pathogens /risks
 - 5.3. Potential to also contribute to reducing **disease and other pathogen** loads/risks

6. **Given the various shifting market drivers, what are your thoughts about the short-medium term prospects for:**
 - 6.1. **Litter reuse** becoming more likely, less likely, or unlikely to change?
 - 6.2. Use of **litter amendments** becoming more likely, less likely, or unlikely to change?
 - 6.3. What about long-term predictions for litter reuse and use of amendments?

7. **We're compiling information on litter amendments for the key purpose of reducing ammonia-related production risks. We're also interested in the potential effects of amendments on food safety and diseases/pathogens.**
 - 7.1. Are there any topics you would specifically like us to investigate in our review?
 - 7.2. Are there any issues currently that could be addressed with litter amendments?
 - 7.3. Should our review include parent farms or only grow-out farms?
 - 7.4. **Can you recommend anyone else that we should contact about litter amendments (Growers, Grower companies, Litter distributors, vets etc.)?**

8. **How do you see the information from this review helping with management of on-farm risks?**
 - 8.1. What is the likelihood that you may make changes to your business or practices regarding litter amendments and litter reuse?

Appendix 2: Detailed summary of selected literature regarding litter amendments

Shaded cells indicate the litter amendment product included in the document

Literature source	Alum	Sodium bisulfate (PLT)	Sulfuric acid clay (PG)	Other amendments	Notes	Focus of testing				
						Ammonia	Production efficiency	Chicken health/welfare	Food safety	Fertiliser value/environment
(Choi and Moore Jr 2008)				Fly ash and aluminium chloride	A variety of litter amendments were assessed and it was determined that those that reduced the litter pH substantially resulted in a decrease in ammonia emissions. The best results observed were for high rate of dry alum (0.98 kg/m ²), which resulted in a 96% reduction in ammonia volatilisation. It was concluded that amendments that have a greater capacity to reduce litter pH have the greater potential to reduce ammonia production. Of the amendments used, the ones that did not reduce pH, such as fly ash, had little to no effect on ammonia emissions. While it was recommended that dry alum was the most successful amendment, it was suggested that potentially all acidifying agents could warrant use.					
(Eugene et al. 2015)					Alum-treated sheds experienced a daily reduction of in-house ammonia concentration of 42% and an overall ammonia emission reduction of 47%. An increase of 287 kg of nitrogen was retained in litter per flock treated with alum when compared to the control. It was suggested alum increased the value of the litter as an inorganic fertiliser due to the increase in total nitrogen content.					
(Hunolt et al. 2015)					A controlled laboratory experiment and a field experiment assessed the effects of PLT on ammonia reduction in litter. The treated litter had an initial application of PLT and a single reapplication. The treated litter had 60% lower ammonia compared to the control. This test treatment also resulted in a 12% increase in nitrogen retention. Nitrogen retention for the field experiment was only significantly better for treated litter after four sequential flocks. Bacterial concentrations were immediately reduced but did not show continued inhibition over time. It was concluded that amendments, such as PLT, can be used to decrease ammonia during the brood stage when applied before chick placement. It was also suggested that reapplications could be beneficial in reducing ammonia concentration during a flock.					

Literature source	Alum	Sodium bisulfate (PLT)	Sulfuric acid clay (PG)	Other amendments	Notes	Focus of testing				
						Ammonia	Production efficiency	Chicken health/welfare	Food safety	Fertiliser value/environment
(Karamanlis et al. 2008)				Zeolite (Clinoptilolite)	This study involved the investigation of using zeolite in litter and feed. The two diets examined were Basal (B) and zeolite (Z); the two bedding types were sawdust (S) and sawdust bedding with zeolite (Sz). By combining these tests, four scenarios were created: BS, BSz, ZS and ZSz. Meat chickens in the ZS, BSz and ZSz treatment groups all showed faster growth rates when compared to the BS group, which were more noticeable by day 28. Ammonia emissions were highest for the ZS group when compared to BSz and ZSz (27 ppm compared to 20.55 ppm and 21.71 ppm, respectively). Ammonia nitrogen concentration was lower in groups where natural zeolite was used. Results suggest that use of natural zeolite was more beneficial to ammonia reduction when used in litter. However, a combination of zeolite in both can be beneficial to meat chickens by increasing litter quality.					
(Line and Bailey 2006)					Alum and PLT were tested to determine their effects on the pathogens <i>Campylobacter</i> and <i>Salmonella</i> , which are naturally found in meat chickens. The amendments were separately tested in five sheds, with each compared to a control, to assess the incidence of <i>Salmonella</i> in chickens. For <i>Campylobacter</i> , it was determined that the use of these acidifying amendments could delay onset. However, <i>Salmonella</i> incidence was unaffected with both treatments. It was recommended that increasing the amount of these treatments could further delay onset, but this may come at large financial cost. Another option proposed was to use these amendments in time-release capsules, which would delay activation.					
(McCroly and Hobbs 2001)				Zeolite (Clinoptilolite)	Clinoptilolite is a natural zeolite that has affinity for ammonium. An application rate of 5 kg/m ² could reduce aerial ammonia concentration by up to 35%. Application to waste and litter has been shown to be more effective than its implementation into feed. This amendment type has shown the capacity to reduce ammonia content in waste and litter; however, to be highly effective, it is required in high quantities, which would be costly.					

Literature source	Alum	Sodium bisulfate (PLT)	Sulfuric acid clay (PG)	Other amendments	Notes	Focus of testing				
						Ammonia	Production efficiency	Chicken health/welfare	Food safety	Fertiliser value/environment
(McWard and Taylor 2000)					An experiment was conducted to assess if acidified clay (Poultry Guard, PG) could achieve similar results to alum and PLT for ammonia reduction, chicken performance, and welfare. All three amendments showed a clear reduction in ammonia concentration for 30 days before losing efficacy. Between the two compositions of PG used (36% and 46%), there was minimal difference in ammonia emissions recorded. Body weight, carcass quality, breast blister score and foot pad score were all significantly improved with use of PG when compared to the control. It was determined that PG was just as effective as PLT and alum when applied in poultry houses.					
(Moore et al. 2000)					This study assessed the use of alum in poultry houses over a three-year period compared to control houses. In total, over 600,000 chickens were weighed; the average weight of chickens in alum-treated sheds was 1.73 kg, which was significantly higher than the 1.66 kg recorded for chickens in the control shed. There was a 73% reduction in soluble phosphorus in runoff water when treated litter was compared to control litter over the trial period. It was determined that the use of alum as a litter amendment not only improved poultry production but also reduced potential impacts of litter on water systems.					
(Moore et al. 2008)					The most significant factors that control the production of ammonia in poultry houses are temperature, moisture content, air exchange rate and pH. Using alum to treat litter decreased ammonia emissions by 75% across the first 2 weeks of a grow-out. Ammonia reductions were smaller than in previous studies, due to different management strategies, especially the use of larger chickens that have higher rates of manure production. Applying alum while litter is in storage or applied to land could reduce the amount of nitrogen lost due to ammonia volatilisation outside of a production shed.					

Literature source	Alum	Sodium bisulfate (PLT)	Sulfuric acid clay (PG)	Other amendments	Notes	Focus of testing				
						Ammonia	Production efficiency	Chicken health/welfare	Food safety	Fertiliser value/environment
(Oviedo-Rondón et al. 2013)					PLT was studied with a variety of different applications rates and strategies. At the highest application rate, ammonia emissions were reduced by 47% throughout an entire production shed. However, despite these reductions, chicken performance was fairly consistent across all application rates and methods. Therefore, it was concluded a decrease in overall ammonia emissions does not necessarily translate to increased production and performance. One recommendation from the author was that PLT application could be limited to just the brooding end when chicks are at their highest risk due to ammonia. A potential reason that chicken performance did not differ much in separate experiments could be that the highest ammonia concentration recorded was 28.1 ppm, which is only just above the recommended limit.					
(Pope and Cherry 2000)					This study applied PLT at a rate 0.24 kg/m ² to a meat chicken house. Ammonia concentration measured in the PLT-treated shed was 6.2 ppm, which is significantly less than the 62.3 ppm recorded for the control. Two weeks after application, the control shed had a concentration of 19.8 ppm compared to the 10.7 ppm for the test shed at the same time. A drop in total bacterial content was also observed, but this reduction lasted only a week after the litter treatment was applied.					
(Pursswell et al. 2013)					In a simulated production environment, PLT was applied multiple times to assess chicken performance, welfare and ammonia concentration. It was determined that when applied biweekly, reductions were recorded at 56.6% and 21.8% at days 42 and 57, respectively. It was determined that live performance was not affected by multiple reapplications. It was recommended that assessing these conditions in commercial conditions would provide valuable information on potential benefits.					
(Rothrock Jr et al. 2008)					From a commercial meat chicken shed, used litter was obtained after the 5th sequential flock. Alum was added at 10% of the litter weight. After 4 weeks, <i>Campylobacter</i> was below the detectable limit (10 ⁴) while still having a concentration of 1.9×10 ⁷ cells/g in the control experiment. By week 8, no <i>Campylobacter</i> were present in either the control or the test. This is due to <i>Campylobacter</i> having poor survivability, and without the constant presence of fresh dropping would die off in these conditions.					

Literature source	Alum	Sodium bisulfate (PLT)	Sulfuric acid clay (PG)	Other amendments	Notes	Focus of testing				
						Ammonia	Production efficiency	Chicken health/welfare	Food safety	Fertiliser value/environment
(Singh et al. 2009)				Urease Inhibitor	A primary step in the breakdown of uric acid into ammonia is facilitated by urease, which converts urea to ammonia. By inhibiting this step with the enzyme inhibitor NBPT, a reduction in ammonia volatilisation should be achieved. A 21-day cage experiment with applications of NBPT at days 0 and 7 resulted in a 10% reduction to total ammoniacal nitrogen (TAN). Other experiments showed minimal reductions. It was concluded that there was inadequate moisture present for NBPT to be effective.					
(Terzich et al. 1998b, 1998a)					Two separate studies assessed PLT in litter. When PLT was applied to litter compared to 31.5% for the control, the death rate due to ascites was recorded at 5.9%. These results indicate that PLT had a positive effect on reducing deaths associated with this condition. In the 2nd study, ammonia concentration was recorded at 53 ppm for the control, and 19 ppm for PLT treatment at 49 days after chick placement. This corresponded to a slight performance improvement with chickens raised on PLT-treated litter weighing 2.312 kg and control chickens weighing 2.204 kg. Other health attributes of chickens, such as air sac scores and damage to tracheal cells, were also improved when chickens were raised on litter treated with PLT.					
(Vicente et al. 2007)					When acidified clay (Poultry Guard, PG) was applied to used litter, the recorded incidence of <i>Salmonella</i> was much lower (0% for low rate and 2.5% high rate) than for the control (27.5% incidence). A replicate experiment using new litter determined that the <i>Salmonella</i> incidence was increased significantly for the control (46%), low dose (23%) and high dose (18%). It was reported that <i>Salmonella typhimurium</i> could survive longer on new litter than on reused litter.					

Literature source	Alum	Sodium bisulfate (PLT)	Sulfuric acid clay (PG)	Other amendments	Notes	Focus of testing				
						Ammonia	Production efficiency	Chicken health/welfare	Food safety	Fertiliser value/environment
(Williams and Macklin 2013)					Three rates of sulfuric acid treatment were applied to litter containing commercially sourced manure. After 96 hours, the ammonia concentrations recorded for treatments were 2.7, 2.4, and 1.1 ppm for low, medium, and high rates, respectively. These ammonia concentrations were all significantly lower than the 20.8 ppm recorded for the control. A <i>Salmonella</i> cocktail was added to these litter experiments. Negative results were recorded for every sulfuric acid test; however, for the control, the <i>Salmonella</i> concentration was found to be 2.7 cfu after 96 hours. Alum treatment also showed promising results for reducing ammonia concentration, and similarly to sulfuric acid, the higher rates did not show increased success. Alum had no effect on bacterial concentrations.					
(Worley et al. 2000)					A high rate (0.976 kg/m ²) and low rate (0.488 kg/m ²) of alum were used to treat litter. Overall, it was determined that using a high rate did not significantly improve results, particularly for total nitrogen in litter, body weight, feed conversion, mortality or production costs. An author recommendation was to implement alum to only the brooding section because chicks are at their highest risk due to ammonia during this phase.					
(Zhang et al. 2011)					Alum treatment resulted in a 30% reduction in ammonia when compared to the control, and managed to maintain a lower litter pH for 35 days after application. These reductions did not result in an improvement to foot pad and hock burns scores; however, for normal stocking density, scores were relatively low.					

Appendix 3: Application rates and method for selected litter amendments

Amendment	Key ingredient	Rate	Pre-application	Application	Ongoing management	Safety ^s
Al ⁺ Clear • Liquid • Poultry Grade Alum • A7 (Chemtrade) (General Chemical ; Moore 2004)	Aluminium Sulphate (dry or liquid form)	0.61–0.73 kg/m ² 0.37–0.49 kg/m ² 5–10% weight of litter	De-cake litter and work litter as normal. Make sure litter is below 30%. Exhaust ammonia and moisture from house after de-caking.	Application should occur 3-5 days before chick placement. Keep ventilation/heating to minimum while applying. Requires de-caking machines, fertiliser spreaders, manure trucks and drop spreaders. Works best when mixed in litter thoroughly.		Goggles, dust mask, gloves, enclosed shoes
Poultry House Natural – ‘pH Natural’ (Heart of Nature)	Alum in a mineral blend of natural elements	0.24–0.37 kg/m ²		Apply to dry litter 0–7 days before placing chicks, depending on litter conditions: <ul style="list-style-type: none"> • if litter is dry, apply to the surface. • if litter is wet, mix into the top 1.25 cm and re-level. 		Use general ventilation and local exhaust. Goggles, gloves, dust mask.

Amendment	Key ingredient	Rate	Pre-application	Application	Ongoing management	Safety ^s
PLT® Poultry Litter Treatment (Jones-Hamilton AG)	Sodium Bisulphate	0.37-0.49 kg/m ² for litter less than a year old 0.49-0.73 kg/m ² for litter more than a year old	Close poultry house to increase ammonia production from old litter. Heating litter will speed up process. Ventilate shed to remove this built-up ammonia. De-cake and remove wet litter.	Apply to top of litter 2-24 hours prior to bed placement. Broadcast or use drop spreader to apply PLT. Do not incorporate into litter. Ventilate house to maintain RH% between 50-70.	PLT can be safely reapplied at any time throughout flock if any issues with regards to ammonia or disease occur.	Goggles, long pants, boots, long-sleeve shirt, gloves, dust mask
Poultry Guard® (PG) (Oil-Dri Corporation of America) (Trinico Ag Inc. 2017)	Sulphuric Acid, in the form of acidified bentonite clay	0.49-0.61 kg/m ² Potentially increase rate when windrowing	Remove as much caking as possible. Wash downs/disinfection must be completed 2 days before PG dressing. Ventilate as much ammonia from previous flock as possible.	Use any type of mechanical spreader. Apply evenly over area to be treated. Always apply before top dressing of litter.	Machinery and equipment should be cleaned after application so no damage occurs. Controlled ventilation for moderation of humidity.	Gloves, eye protection, dust mask, long-sleeve shirt, long pants, plastic boot cover
Klasp™ (Kemira Water Solutions) (Kemira; Reeder and Johnson 2008)	Iron Sulphate	0.37-0.49 kg/m ²	Prior to application of Klasp, litter should be de-caked or rototilled. Should be applied 4 days before bird implementation. Heating is not required before application.	Top coating is adequate with incorporation into the litter not recommended. Moisture activates the amendment therefore some moisture in litter is required.		Gloves, long-sleeve shirt, long pants, dust mask and goggles

Amendment	Key ingredient	Rate	Pre-application	Application	Ongoing management	Safety [§]
Litter Life (Southland Organics 2018)	Biological Blend (Humic, Fulvic acid), high in carbon	0.2 L/m ²	Seal house after removal of previous flock and maintain higher heat to release ammonia from litter. Ventilate shed to purge all ammonia. De-cake litter before application.	Apply several days before chick placement. Can be used with PLT. Dilute 1 gallon of concentrate with 9 gallons of water. Apply 3-24 hours after dilution using liquid spray system to uniformly cover entire surface.	Follow standard ventilation procedure before and after bird placement.	
Poultry House Treatment (BioProtect 2018)	Natural Bacterium, Lipid Peptides	0.01 L/m ²		Treatment should be applied on a monthly basis and immediately prior to bird placement. Product can be diluted before application to achieve optimal coverage.		
Stalosan®F (Vilofoss, Denmark)	Phosphates, ferrous sulfate; copper sulfate; diiron trioxide; essential oil	<u>Powder:</u> 50–100 g/m ² once per week <u>Granulated:</u> 250–500 g before chick placement		Apply evenly to the litter surface before chick placement.	Regular reapplication (weekly) as required. Previously untreated areas may require additional treatments.	Dust mask, gloves, and wash hands after use.

[§]A Material Safety Data Sheet (MSDS) must be obtained before using any product

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